

GENERALIZATION PEAK SHIFT FOR AUTOSHAPED AND OPERANT KEY PECKS

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Pigeons acquired discriminated key pecking between 528- and 540-nm stimuli by either a response-reinforcer (operant group) or a stimulus-reinforcer (autoshaped group) contingency, with other training-schedule parameters comparable over groups. For the birds in the operant group, key pecks intermittently produced grain in the presence of one hue on the key (positive stimulus) but not in the other (negative stimulus). For the birds in the autoshaped group, pecking emerged when grain was intermittently presented independently of key pecking during one key color but was not presented during the other key color. Two independent contingency assays, peck-location comparisons and elimination of differences in reinforcement rate, confirmed the effectiveness of the two training procedures in establishing operant or respondent control of key pecking. After reaching a 10:1, or better, discrimination ratio between key pecks during the two key colors, the birds received a wavelength generalization test. Criterion baseline key-peck rates were comparable for operant and autoshaped groups prior to testing. On the generalization test, performed in extinction, all birds pecked most at a stimulus removed from the positive training stimulus in the direction away from the negative stimulus. In testing, autoshaped "peak" rates (24.5 to 64.9 pecks per minute) were from 33% to 80% higher than rates in the presence of the training stimuli. Respondent peak shift rarely has been reported heretofore, and never this consistently and robustly. These results further confirm the similarity of perceptual processing in classical and operant learning. They are discussed in terms of Spence's gradient-interaction theory and Weiss' (1978) two-process model of stimulus control.

Key words: stimulus generalization, peak shift, autoshaping, operant-respondent comparisons, contingency assays, intradimensional color discrimination training, key peck, off-key peck, pigeons

The slope of a generalization gradient, as well as where it peaks, is frequently used to reveal the nature of the stimulus control generated by the discrimination training preceding the test. When a response is under interdimensional stimulus control, response probability progressively decreases as the test stimulus is removed from the training stimulus along the continuum being studied. This excitatory stimulus generalization has been reported in classical (e.g., Hovland, 1937; Pavlov, 1927) and instrumental (e.g., Guttman & Kalish, 1956; Hanson, 1959) conditioning. In Hanson's study, pigeons' key pecks were reinforced when the key was illuminated at a hue of 550 nm (S+) in a procedure that in-

cluded brief periods of darkness during which responding was ineffective (S-). In a subsequent generalization test, in which wavelengths within the range of 480 nm and 620 nm were presented, a roughly symmetrical gradient of responding was produced with a maximum at 550 nm (S+).

Hanson (1959) was among the first to explore the effect of intradimensional discrimination training on stimulus control. His interdimensional group was described above. In one of his intradimensional groups, pigeons' key pecks were reinforced at 550 nm (S+) and not reinforced at 555 nm (S-). This discrimination training displaced the gradient's peak from S+ in a direction away from S-, the stimulus associated with extinction (EXT), in a subsequent generalization test. This peak shift was profound, with approximately four times as many pecks emitted at 540 nm than at S+ (550 nm).

Peak shift has been demonstrated many times in operant conditioning with positive reinforcement (see Purtle, 1973, and Weiss, 1978, Table 3, for reviews) and has also been reported in situations in which responding was

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maintained by shock avoidance by treadle pressing in pigeons (Bushnell & Weiss, 1980) and by bar pressing in rats (Weiss & Schindler, 1981). A notable contrast exists between the often-demonstrated robust and reliable peak shift following intradimensional operant training and the rarity, weakness, and inconsistency of peak shift following respondent intradimensional training. Attempts to show peak shift in respondent procedures are described in detail below.

In one classical conditioning study, Liu (1971) gave 8 rabbits intradimensional differential conditioning in which a 1200-Hz tone (CS+) preceded a brief shock to the infraorbital region of the eye, activating the nictitating membrane. A 1600-Hz tone (CS-) was never followed by shock. A generalization test produced symmetrical gradients, with a peak at CS+, similar to those produced by a group of rabbits that received interdimensional (CS+ only) training.

Hupka, Liu, and Moore (1969) employed intradimensional classical discrimination training in a design essentially similar to that of Liu (1971), with the addition that CS+/CS- separations were manipulated over six groups of rabbits. These counterbalanced stimulus separations were 400 versus 1600 Hz, 1600 versus 2800 Hz, and 2800 versus 4000 Hz. Of the 12 mean stimulus generalization gradients reported (two for each group over 2 days), only one showed a peak shift away from CS-. This occurred for the group for which CS+ was 1600 Hz and CS- was 400 Hz, and occurred only in the first test. Unfortunately, with neither individual gradients nor statistical comparisons reported, it is difficult to evaluate the significance of this one instance of peak shift.

Moore (1972, pp. 214-217) sought additional information on the effects of differential classical conditioning on generalization by running small squads of rabbits under a wide range of intradimensional training and testing procedures. However, only 5 of 30 subjects produced peak shift in their first generalization test, with this number increasing to 11 when all tests (ranging from one to three per subject) were considered. Moreover, even when Moore and his associates did obtain peak shift with the rabbit's nictitating membrane reflex, it usually occurred when S+ was a higher frequency tone than S-, and not vice versa. Cowan (1968) also reported this asymmetry

when using counterbalanced CSs of 2000 and 3000 Hz in differential eyelid conditioning with rabbits. Thus, in what would be considered a traditional classical conditioning preparation, the peak shift phenomenon is suggested, but the findings are inconsistent, weak, and unidirectional.

Keller (1974) applied an analytical technique introduced by Catania (1973) to identify control by stimulus-reinforcer and response-reinforcer contingencies in the analysis of behavioral contrast. In this "topographical tagging" paradigm, the operant manipulandum, whose operation produces reinforcers, is separate and distinct from the stimulus presentation key that comes to control stimulus-directed pecks. These latter pecks are monitored but have no scheduled consequences. The generalization of intradimensionally controlled stimulus-key directed pecks was investigated by White and his associates (Skelton & White, 1982; White & Braunstein, 1979; White & Thomas, 1979) and Weiss and his associates (Bushnell & Weiss, 1980; Weiss & Dacanay, 1982). Line-tilt and wavelength dimensions were represented that can be distinguished according to whether the stimulus-directed behavior and operant behavior were "homogeneous" (both key pecks) or "heterogeneous" (stimulus-directed key pecks and operant treadle presses). The topographical tagging studies using homogeneous behavior were performed by White and his associates, whereas Weiss and his associates performed their studies with heterogeneous operant and stimulus-directed behavior. In general, the control of stimulus-key responding roughly paralleled that of operant-key responses, but was weaker and less consistent. Being concerned here with respondent stimulus control, our discussion of these studies will emphasize the stimulus-key responses.

White and Braunstein (1979) trained 4 pigeons on an intradimensional discrimination in which a 67.5° line (S+) was projected on the stimulus key when operant-key responses produced food on a variable-interval (VI) 30-s schedule. A 22.5° line (S-) was projected on the stimulus key during EXT. In a line-tilt generalization test, 2 birds produced peak shift on the stimulus key and 1 produced clear area shift. (Area shift refers to the generalization test outcome in which S+ controls the highest rate, but the gradient is asymmetrical because fewer responses are produced by the stimuli

on the S- side of S+ than by the stimulus values on the other side.) However, stimulus-key rates were exceedingly low in testing. Among the birds showing peak shift, the fastest rate was under three pecks per minute, less than 1/min higher than the rate to S+.

White and Thomas (1979) conducted a systematic replication of White and Braunstein's (1979) study that was designed to produce more stimulus-key directed behavior in testing. Their birds received wavelength discrimination training with reinforcement maintained in S+ during generalization tests. Peak shift was produced in 60% of the three tests presented to each of 2 pigeons, with peak rates in the range of 10 to 15 pecks per minute. The remainder showed clear area shift.

Skelton and White (1982) replicated the White and Braunstein (1979) study with 3 birds. The stimulus-key wavelengths used in training were the same as those used by White and Thomas (1979). None produced peak shift on the operant or stimulus keys, although all showed area shift on the operant key and 2 showed this shift on the stimulus key. The design of this experiment also revealed that "... stimulus-key responding was suppressed when brief timeout periods were contingent on responses directed at the stimulus signalling reinforcement for the operant key" (p. 275), demonstrating that stimulus-key pecks were sensitive to control by an operant contingency. Skelton and White also suggested that stimulus-key responding in the topographic tagging paradigm may, to some extent, reflect generalization of operant-key responding.

In the heterogeneous topographical tagging studies by Weiss and his associates, the operant was treadle pressing with the S+ and S- wavelengths presented on a key directly above the treadle at about the height of a pigeon's beak. Bushnell and Weiss (1980) used multiple VI EXT training similar to that of White and his associates, and reported peak shift for the operant response (treadle pressing) for all 6 pigeons. However, only 1 of their birds produced peak shift on the stimulus key, with 3 others showing clear area shift.

Weiss and Dacanay (1982) trained 3 birds on a chained schedule in which treadle pressing in the initial-link wavelength (S2) produced the terminal-link wavelength (S1). Reinforcers were delivered in S1 according to a differential-reinforcement-of-other-behavior (DRO) schedule applied to the treadle press.

During S1, stimulus-directed key pecking was robust, with rates ranging from 17.2 to 136.3 pecks per minute and S2:S1 peck discrimination ratios ranging from 16:1 to 146:1. In spite of these powerful intradimensional discriminations with autoshaped pecks, only 1 bird produced area shift. The other 2 birds produced very steep, symmetrical, "knife-edge"-like gradients around the food-associated stimulus.

What might be concluded from these topographic tagging studies about the stimulus control of stimulus-directed responding? It appears that peak, or at least area, shift was produced by these responses in the homogeneous and heterogeneous training paradigms, but these shifts were rather weak and fragile phenomena. Taking the first generalization test of the total of 18 birds used in these studies, only 4 produced peak shift, with 8 others showing area shift. However, area shift and peak shift do not necessarily reveal comparable processes. Area shift can result from the fact that S- differentially reduces the number of responses on the S- side of S+ while having little effect on the generalized behavior to stimulus values on the other side of S+. Therefore, unless specifically evaluated in relation to interdimensional control, area shift does not offer convincing evidence of increased excitatory control to stimuli beyond S+ in a direction away from S-, as peak shift does.

One should also consider, when analyzing results from the topographic tagging design, that it is rather difficult to characterize confidently the contingencies controlling the stimulus-directed pecks as purely respondent, because (a) the stimulus-directed pecks are sensitive to operant punishment (timeout) contingencies (Skelton & White, 1982); (b) at all stimulus values, but particularly at S+ and beyond, there can inevitably be competition between responses on the operant manipulandum and the stimulus key; and (c) to the extent that operant responses can generalize to the stimulus key, the characterization of these latter types of behavior as respondent may be challenged. Although the topographical tagging studies have produced occasional instances of peak shift for the autoshaped peck, a more traditional intradimensional autoshaping study would be less susceptible to these problems, if performed adequately.

Nallan, McCoy, Pace, and Welch (1979) reported differential intradimensional auto-

shaping along the line-tilt dimension. They trained 3 pigeons on a multiple variable-time (VT) extinction (EXT) schedule in which response-independent reinforcers were delivered in the presence of one line orientation (45°) but not during an orientation 30° removed (15°). This was meant to establish the discrimination solely on the basis of a respondent contingency. After this training, peak shift was not obtained in a line-tilt generalization test. In fact, all 3 birds responded at substantially lower rates to the stimulus one step removed from their VT stimulus, in the direction away from the EXT angle, than to the VT stimulus itself. This makes it unlikely that the generally applied gradient interaction dynamics of peak shift (Rilling, 1977; Spence, 1937; Weiss, 1978) were responsible for the area shift reported by Nallan et al. Their findings are consistent with previous difficulties in producing reliable peak shift with autoshaped pecks or with traditional classical conditioning paradigms.

The generalization test data reported by Nallan et al. (1979) would have been more informative if they had included a condition in which the line-tilt discrimination was established through an operant contingency. This is an important control in light of previous difficulties in obtaining peak shift on a line-tilt dimension (Hearst, 1968, 1971) and the degree to which peak shift is stimulus and parameter bound (Purtle, 1973). Moreover, even if this operant conditioning group existed, independent assays of the control actually generated in the two groups would be essential if the generalization results were to be linked unambiguously with operant or respondent discriminative control.

Most of the stimulus control phenomena produced after operant training have also been demonstrated with autoshaping. For example, excitatory and inhibitory gradients for autoshaped pecks following interdimensional discrimination training have been reported (Tomie, Davitt, & Engberg, 1976; Wessells, 1973). Further, the effects of extradimensional training on the shape of generalization gradients were shown to be similar in the autoshaping paradigm when respondent contingencies were manipulated (Tomie et al., 1976) to those obtained when operant contingencies were also changed (Thomas, Freeman, Svinicki, Burr, & Lyons, 1970). This comparability was demonstrated under differential,

nondifferential, and single-stimulus extradimensional training. On the basis of these parallels in stimulus control for respondent and operant contingencies, as well as for most other conditioning phenomena (Kimble, 1961; Mackintosh, 1974), generalization peak shift should be the likely outcome after intradimensional respondent discrimination training when stimulus parameters are appropriately chosen and care is taken to insure control only by the relevant stimuli.

The present experiment compared the effect of discrimination training under operant and respondent contingencies on postdiscrimination generalization gradients. Except for the contingency in the component associated with grain delivery, stimulus parameters and rates of reinforcement were kept comparable between operant and respondent procedures. The 12-nm conditioned stimulus (CS+:CS-) difference employed is close to that proven effective in producing operant peak shift in this laboratory (Bushnell & Weiss, 1980; Weiss & Dacanay, 1982, Experiment 2), but to our knowledge pure autoshaping has not yet been reported with such small wavelength differences.

The instrumental procedure was a multiple VI EXT schedule under which pecking intermittently produced grain when the key was illuminated with one hue but not when it was illuminated with the other. The autoshaping procedure was a multiple VT EXT schedule under which grain was presented independently of the pigeons' behavior in one hue and no grain was presented in the other. The goal of this training was to establish comparable intradimensional key-peck discriminations for two groups of pigeons. However, for the instrumental procedure an operant contingency was programmed in S+, whereas for the autoshaped procedure a respondent contingency operated in CS+. Prior to testing, component durations, reinforcement frequency, peck rates, and discriminative control were comparable between the two conditions.

Special precautions were taken to insure control by key color and not by intensity of the stimulus, temporal parameters of the stimulus components, apparatus sounds related to stimulus presentations, or extraneous stimuli. In addition, the effectiveness of these training procedures in establishing operant and autoshaped key pecks in the two conditions, re-

spectively, was evaluated with a variety of assays traditionally used to distinguish between operants and respondents. These included key-peck accuracy (Barrera, 1974; Jenkins, 1981) and manipulation of the stimulus-reinforcer correlation (Gamzu & Williams, 1971, 1973; Rescorla, 1968).

METHOD

Subjects

The subjects were 11 experimentally naive Silver King or White Carneau pigeons 1 to 3 years old at the start of training. The pigeons were trained and tested at 75% to 85% of their free-feeding weights. They were maintained on a diet of mixed grain that was also used for reinforcement. They were fed whatever extra grain was needed to maintain them at their predetermined weights directly after a training session. Water and grit were continuously available in the home cage.

Apparatus

The training chamber measured 30.5 cm high, 34.3 cm long, and 24.1 cm wide. Its side and back walls were made of white 0.6-cm translucent plastic. The hinged top was 0.6-cm clear plastic perforated with ventilation holes, and the floor was composed of 1-cm stainless-steel hardware cloth. A 2-cm-diameter clear plastic stimulus key, made translucent by light sanding, was centered on the white aluminum front wall 19.5 cm above the floor. The hue stimuli were projected on the back of this key. Surrounding this key was a 0.5-cm white plastic doughnut-shaped disc that was also reactive to pecks. Pecks that contacted this area were counted as "off-key" pecks. This made the on-key area 3.1 cm² and the surrounding off-key area 3.9 cm². "Border" pecks that activated both keys were not differentially counted. A force of approximately 0.15 N operated the normally closed switches behind each key.

A food magazine aperture, 5 cm wide and 6 cm high, was located below the key, with the lower edge of this opening 3.5 cm from the floor. When the hopper was elevated, the aperture was illuminated by a 28-V GE 509K bulb. The chamber was illuminated by a 6-in. 120-V showcase bulb centered vertically behind the rear white plastic wall. The intensity of this bulb was adjusted to make the rear wall

just bright enough to eliminate keylight projections. To accomplish this, the bulb was operated through a variac at 75 V. The illumination of the front and rear walls, measured by a Simpson Model 408-2 Illumination Level Meter, whose sensor was located midway between them, was 0.233 and 1.153 lux, respectively. The chamber was enclosed in a sound-attenuating chest based on the design reported by Weiss (1970). An exhaust fan was mounted on an outside wall of this chest over the ventilation sound baffle. A PDP-8A® computer, located in an adjacent room, was programmed with SUPERSKED® to present events according to planned contingencies. Data were recorded by the computer and a cumulative recorder.

The visual stimuli projected on the stimulus key were generated by Bausch and Lomb interference filters (44-78 series) whose peak wavelength transmissions were nominally indicated as 500, 510, 520, 530, 540, 550, 560, and 570 nm. However, independent measurement of the peak transmission values of these filters with a Varian Series 634 Spectrophotometer showed them to be 498, 510, 522, 528, 540, 548, 558, and 566 nm, respectively. Kodak 0.1 and 0.2 neutral density filters (No. 9 series) were also used. The illumination source was a GE 18A/T10/2P-6-v microscope illuminator bulb with ribbon filament and an output of 1,800 lumens. The collimated monochromatic light transilluminated the translucent stimulus key. The lamp source was 50 cm from the key. Each of the 10 filters (8 wavelength and 2 neutral density) was placed in a seat that could be raised by activating a solenoid. When a seat was raised, the filter it held was placed in the path of the light beam. This is the same projection system used by Bushnell and Weiss (1980) and Weiss and Dacanay (1982), with Bausch and Lomb filters substituted for Dittic filters.

Procedure

The pigeons were first trained to eat grain from the food hopper. The hopper was raised and the aperture illuminated until the pigeon located the grain and ate it for approximately 5 s, after which the hopper was lowered and the aperture light shut off. This hopper training continued until the bird was eating from the hopper promptly after aperture illumi-

nation. Of the 11 birds, 5 were assigned to the operant group and 6 to the autoshaped group. Training progressed for both groups so as to reach a terminal baseline schedule with similar characteristics except for the reinforcement contingency operating in the presence of the CS+ or S+ stimulus. However, during early training, component durations were used that encouraged acquisition of the target contingency (Terrace, Gibbon, Farrell, & Baldock, 1975). Thus, components with reinforcement were initially shorter for the autoshaped than for the operant group, and those without reinforcement were longer.

Special precautions were taken to insure control by key color and not by intensity of the stimulus, solenoid activations, or other regularities of the training procedure as follows:

1. When going from one component to the next, the key was darkened for 1 s by raising a black slide that blocked the light beam while relevant solenoids operated to get the appropriate filter in the light path. Thus, a briefly darkened key, or the solenoid activations necessary for filter change, could signal a component change. To control for this possibility, during both S+ and S- components the key was occasionally darkened for 1 s, with all associated solenoid activations. These "pseudotransitions" were presented, randomly, on average of once every 40 s. They were introduced into the S- components early in training and into the S+ components after the discrimination began to stabilize.

2. Although the two colors projected on the key looked comparably bright to the experimenters, one could not conclude that this was also true for the pigeons. To control for potential discriminations on the basis of brightness rather than hue, and the real possibility that test hues would differ in brightness from training stimuli, brightness was made an uncorrelated dimension. From early in training, the 0.1 and 0.2 neutral density filters were raised and lowered independently of each other on average of every 15 s. This served to change the brightness of the keys many times during each session without regard to the wavelength stimulus present, while further making solenoid operation an irrelevant factor in stimulus control. When the illumination sensor was placed directly in front of, and almost touching, the key for both training hues (528 and 540 nm), the reading was 0.186 lux when neither

neutral density filter was raised and 0.139 lux when both were raised.

3. To minimize the likelihood of subjects' behavior coming under temporal control of the stimulus components, the durations of these stimuli were varied around mean values. Some of the final baseline components were comparable to the 45-s durations presented in testing.

4. When a pigeon's discrimination began to stabilize, the percentage of positive components in which reinforcement was received was gradually reduced to 75% on average. This was done to minimize the behaviorally disruptive effects the transition from training to the generalization test performed in extinction might produce, to give us an indication in training of the influence on stimulus control of reinforcement presentations, and to produce more test behavior by increasing resistance to extinction.

Operant group. After hopper training, these pigeons were placed in the chamber with the S+ (528 or 540 nm) keylight on continuously. Key pecking was generated through differential reinforcement of successive approximations, usually within one session. After a session of 35 to 45 key-peck-contingent reinforcements on a continuous schedule, a multiple variable-interval 10-s extinction schedule (mult VI 10 s EXT) was introduced. S+ and S- were counterbalanced across subjects over keylight wavelengths of 528 and 540 nm. Initial S+ durations averaged 30 to 40 s, with these components ranging from 50% to 150% of the mean within a session. Initial S- component durations were chosen that did not overly disrupt a bird's pecking in S+. These were 80, 120, and 40 s for Birds 2, 5, and 9, respectively. S- component durations were typically within 50% to 200% of the mean, with only occasional shorter durations.

As the cumulative records and peck rates revealed that a discrimination was developing, the VI schedule was gradually increased through VI 15 and VI 22 until VI 30 was reached. On all VI schedules, interval durations were arranged to avoid systematic sequencing among durations. The limits of all VI schedules were 1 s to three times the mean. S+ and S- durations were also gradually modified as discriminative control developed until they were approximately in a 1:1.5-2 ratio. To reduce Bird 2's pecking in S-, late

in training a contingency was introduced that required no response during the final 10 s of each S- component before the component was terminated.

Final baseline. On the final operant-training baseline schedule, the mean S+ duration was 60 s for all birds, and the mean S- duration was 120, 90, and 90 s for Birds 2, 5, and 9, respectively. A VI 30-s food schedule operated in S+. Training continued until the S+ key-peck rate was at least 10 times the S- rate for four consecutive sessions, with no trend in rates. Then a stimulus generalization test was administered. Birds 2, 5, and 9 received 18, 30, and 32 mult VI 30-s EXT sessions, respectively. One bird in the operant group was eliminated prior to testing because, after 18 sessions of intradimensional training, its S+/S- discrimination ratio had reached only 1.6:1.

Stimulus generalization test. This test consisted of 12 randomized blocks of eight stimuli. Each block contained 45-s presentations of stimuli of 498, 510, 522, 528, 540, 548, 558, and 566 nm. The order was made unsystematic within each block of eight stimuli, with care taken to avoid long series of positive or negative stimuli that might produce induction or contrast effects. A 1-s dark key separated successive stimulus presentations, making each test block 368 s long. Testing commenced after a subject was run on its baseline schedule, with reinforcement, for 15 to 20 min. Reinforcement, as well as pseudotransitions and the operation of neutral density filters, was discontinued during testing. The complete 73.6-min test was administered in one session. After testing, a bird was returned to its final operant baseline schedule for several days.

Autoshaped group. Following hopper training, the pigeons were placed on a schedule in which, on the average of once every 165 s, the CS+ replaced the CS- for 15 to 21 s. Ten seconds into the CS, the hopper was raised for approximately 3 to 5 s, with the CS remaining on for 2 to 6 s after the hopper was lowered and the aperture light extinguished. The pigeons received about 36 CS+-grain pairings during each session, and were exposed to this contingency until pecking emerged. For the initial birds in this group, including Bird 3 who met criterion, this was entirely automated. However, our observations revealed that with the automated procedure, CS+-grain pairings were often presented when the bird wasn't

facing the front wall (where the key was located). This seriously interfered with training, perhaps because of the small wavelength differences employed in this experiment. Therefore, the contingency described above was slightly modified such that CS+ (key-color change)-grain pairings were initially presented when the pigeon was facing the front wall. Prior to instituting this modified initial training procedure, 2 birds were eliminated from this group because pecks were not elicited by the CS+ within eight sessions. They engaged in "bobbing" behavior that appeared to be under the control of some combination of the auditory and visual aspects of the 1-s dark-key stimulus transitions and the hopper operation.

After key pecking emerged on the contingency described above, which usually took only two to four sessions on the modified procedure, the CS was lengthened to average 20 s, not counting hopper durations, and the extinction component continued to average 165 s. During the CS a VT 10-s grain presentation schedule operated. As differential control emerged, the length of the CS+ and the value of the VT schedule were gradually increased while the inter-CS period (CS-) was gradually decreased. The terminal training schedule was a multiple VT 30-s EXT schedule where CS+s averaged 60 s and CS-s averaged 105 s, with the within-session range of these component durations like those described earlier for the operant group. When key pecks occurred at 10 times the rate in CS+ as in CS- for four consecutive sessions, the same stimulus generalization test administered to the operant group was given to the autoshaped group. After testing, a bird was returned to its final autoshaping baseline schedule for several days.

Birds 3, 18, and 19 received 52, 7, and 9 sessions on the mult VT 30-s EXT schedule, respectively, prior to testing. At least some of Bird 3's additional training sessions can be attributed to the fact that many of the control procedures, such as pseudotransitions and neutral density filter operation, were introduced and perfected during its sessions.

Two birds did not form a stable discrimination between CS+ and CS- and therefore were not tested. One of these reached only a 3.8:1 discrimination between CS+ and CS- after 34 sessions on mult VT 30 EXT under the automated acquisition procedure because

Table 1

Response rates (pecks per minute) for the last 4 days of discrimination training for birds of the operant and autoshaped groups.

Subject	S+		S-		Off key as % of on key
	On key	Off key	On key	Off key	
Operant group					
2	98.2	33.5	7.4	5.8	34.1
5	88.8	37.0	8.8	6.9	41.7
9	74.6	1.6	5.3	1.0	2.1
<i>M</i>	87.2	28.8	7.2	4.6	26.0
Autoshaped group					
3	64.4	40.7	2.9	2.9	63.2
18	102.9	68.0	8.2	4.3	66.1
19	60.0	66.9	5.6	2.9	115.5
<i>M</i>	75.8	58.5	5.6	3.4	80.3

pecks appeared to be prompted by pseudo-transitions in CS-. Bird 17, who acquired pecking on the modified acquisition procedure, reached a CS+:CS- discrimination ratio of 15:1 after only 3 days on mult VT 30 EXT when the hopper bulb burned out during a training session. The equipment malfunction severely disrupted this bird's discrimination. With nine additional training sessions, its discrimination ratio returned to no better than 5:1, and its behavior in CS- was clearly less orderly than before the mishap.

Behavioral assays for contingency control. To assist in interpreting the results of these generalization tests, independent assays were introduced to distinguish whether our training procedures were indeed successful in generating different types of control in the autoshaped and operant groups. First, the distribution of on- and off-key pecks by members of the two groups were compared. Also, following the generalization test and return to baseline sessions, a VT 30-s schedule of grain presentation was introduced in what were previously the extinction components. Thus, the procedure for the autoshaped pigeons was now a mult VT 30-s VT 30-s schedule and the procedure for the operant pigeons was a mult VI 30-s VT 30-s schedule. Birds were run on these schedules until they pecked at less than two pecks per minute for 2 days or their pecking showed no downward trend. Next they were returned to their pregeneralization test baselines for several days, either mult VT EXT (autoshaped group) or mult VI EXT (operant group).

RESULTS AND DISCUSSION

Baseline Training and Generalization Tests

The terminal, pregeneralization test, baseline key-peck performance is presented in Panel I of Figure 1 for the birds of the operant group and in Panel I of Figure 2 for the birds of the autoshaped group. The discriminations between positive and negative stimuli are comparable for the two groups, with their absolute key-peck rates overlapping considerably. Table 1 presents these response rates averaged over the last 4 days of discrimination training for each subject. Rates for the operant group ranged from 74.6 to 98.2 pecks per minute ($M = 87.2$), and the rates for the autoshaped group ranged from 60.0 to 102.9 pecks per minute ($M = 75.8$). However, these groups differed in the number of off-key pecks relative to on-key pecks, but these data will be discussed later when contingency assays are considered.

Figure 3 presents the absolute generalization gradients for the operant and autoshaped groups. Peak shift was unequivocally produced by all subjects in both groups for both on- and off-key pecks. This is the most robust and consistent report of peak shift for an autoshaped response to date, and one of the few instances of operant peak shift with training stimuli in this range of the spectrum. The highest peck rate to a stimulus removed from S+, in a direction away from S-, was significantly greater than the rate to S+ for the autoshaped, $t(2) = 4.42$, $p = .048$, and the operant, $t(2) = 6.63$, $p = .022$, groups. The relative gradients (Figure 4) show that for each bird, irrespective of group, the shapes of the on- and off-key peck gradients are overlapping and indistinguishable from each other.

Contingency Assays

Key-peck accuracy. A number of investigators have observed that autoshaping is often characterized by off-key pecking (Barrera, 1974; Jenkins, 1981; LoLordo, McMillan, & Riley, 1974). In fact, a majority of Jenkins' pigeons produced over four times as many off-key pecks, relative to on-key pecks, under automaintenance than under intermittent operant reinforcement. Table 1 presents off-key and on-key peck rates for operant and autoshaped birds during criterion baseline sessions. The difference between groups is dramatic. In absolute terms, as well as relative to on-key

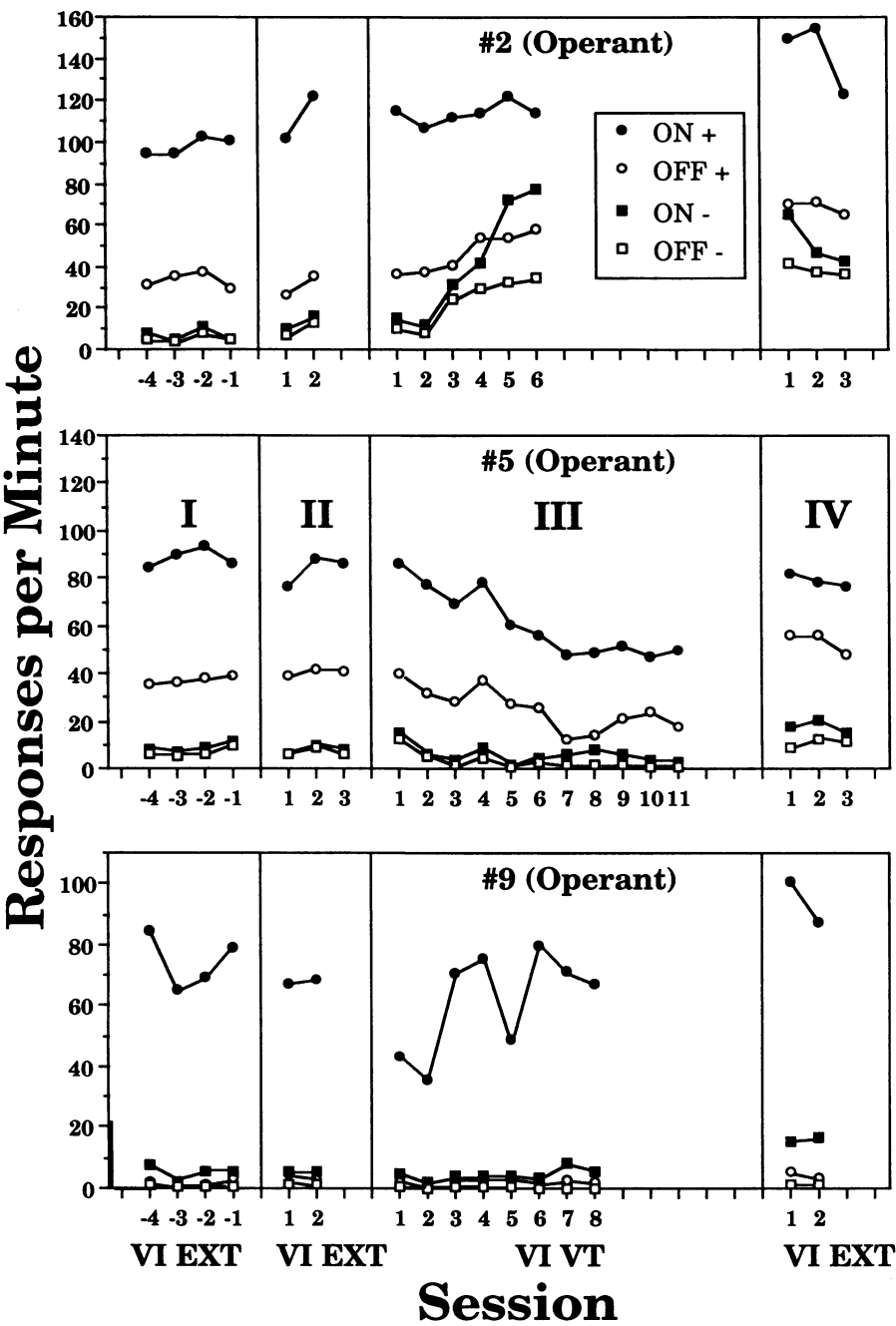


Fig. 1. Responses per minute for the birds trained in the operant procedure, for the last four baseline sessions (I), posttest sessions (II), contingency assay sessions with the mult VI 30-s VT 30-s schedule (III), and sessions with the mult VI 30-s EXT baseline (IV). In each panel, on-key and off-key peck rates are shown.

rates, all autoshaped birds had more off-key pecks than any operant bird. On average, for the autoshaped group off-key peck rates in CS+ were 80.6% of on-key rates. In comparison, during S+ this figure was only 28.6% for

the operant group, a 52% difference between groups.
A measure of the behavioral stability of each subject's key-pecking localization could increase our confidence in this measure of con-

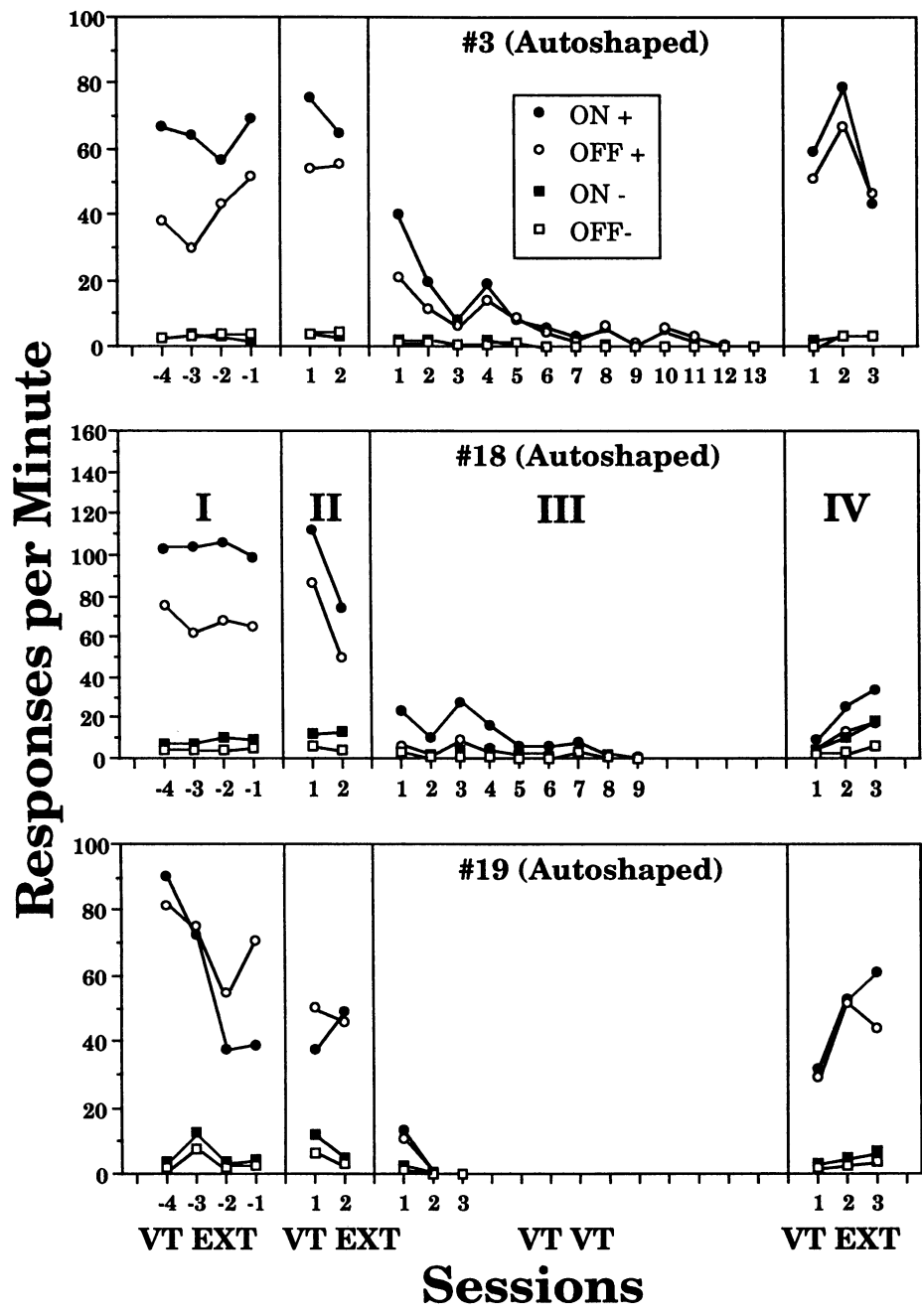


Fig. 2. Responses per minute for birds trained in the autoshaping procedure, for the last four baseline sessions (I), posttest sessions (II), contingency assay sessions with the mult VT 30-s VT 30-s schedule (III), and sessions with the mult VT 30-s EXT schedule (IV). In each panel, on-key and off-key peck rates are shown.

tingency control. Table 2 presents each bird's off-key pecks, as a percentage of its on-key pecks, to S+ during criterion baseline sessions and during the generalization test at its S+ value and the stimulus value controlling its peak rate (S++). The stability of each subject's key-peck accuracy over these three critical instances is striking, as is the consistent overall difference between operant and autoshaped groups. Over these three conditions, the

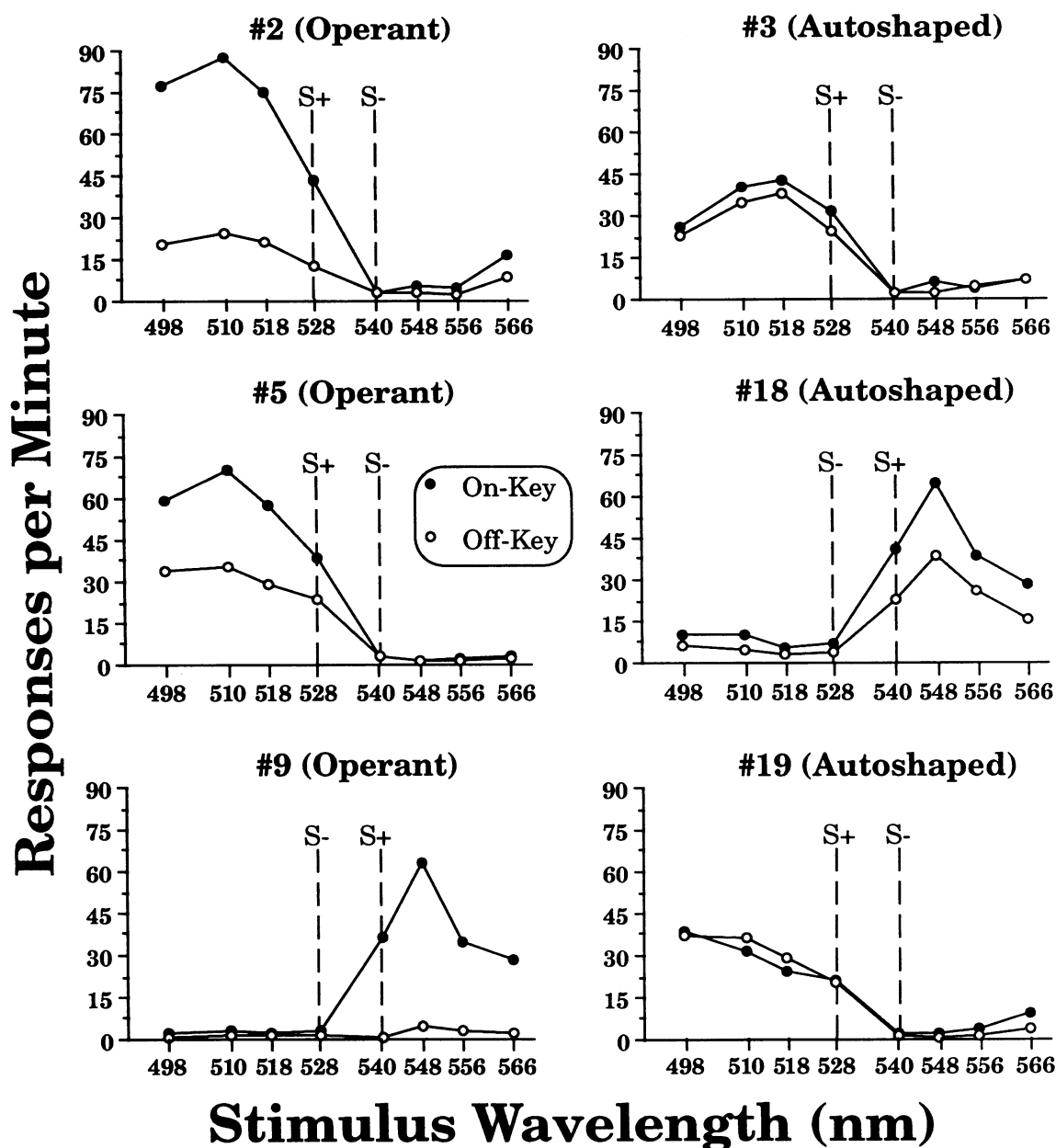


Fig. 3. Stimulus generalization gradients for birds in the operant group (left) and birds in the autoshaped group (right). Reinforced and nonreinforced training stimuli are indicated for each bird with their on-key (filled circles) and off-key (open circles) rate at each test value.

autoshaped group produced a significantly greater proportion of off-key pecks than the operant group, $F(1, 8) = 7.87$, $p < .05$. The differential effects on peck location of operant and respondent contingencies were dramatically revealed. Taken in conjunction with the differential-nondifferential contingency assay presented below, the findings of the current

experiment further validate key-peck accuracy as a measure of contingency control.

Differential-nondifferential association assay. The finding that a differential correlation between CS+ and the unconditioned stimulus is necessary for conditioned suppression to be maintained (Rescorla, 1968; Wagner, 1969) has been extended to the analysis of auto-

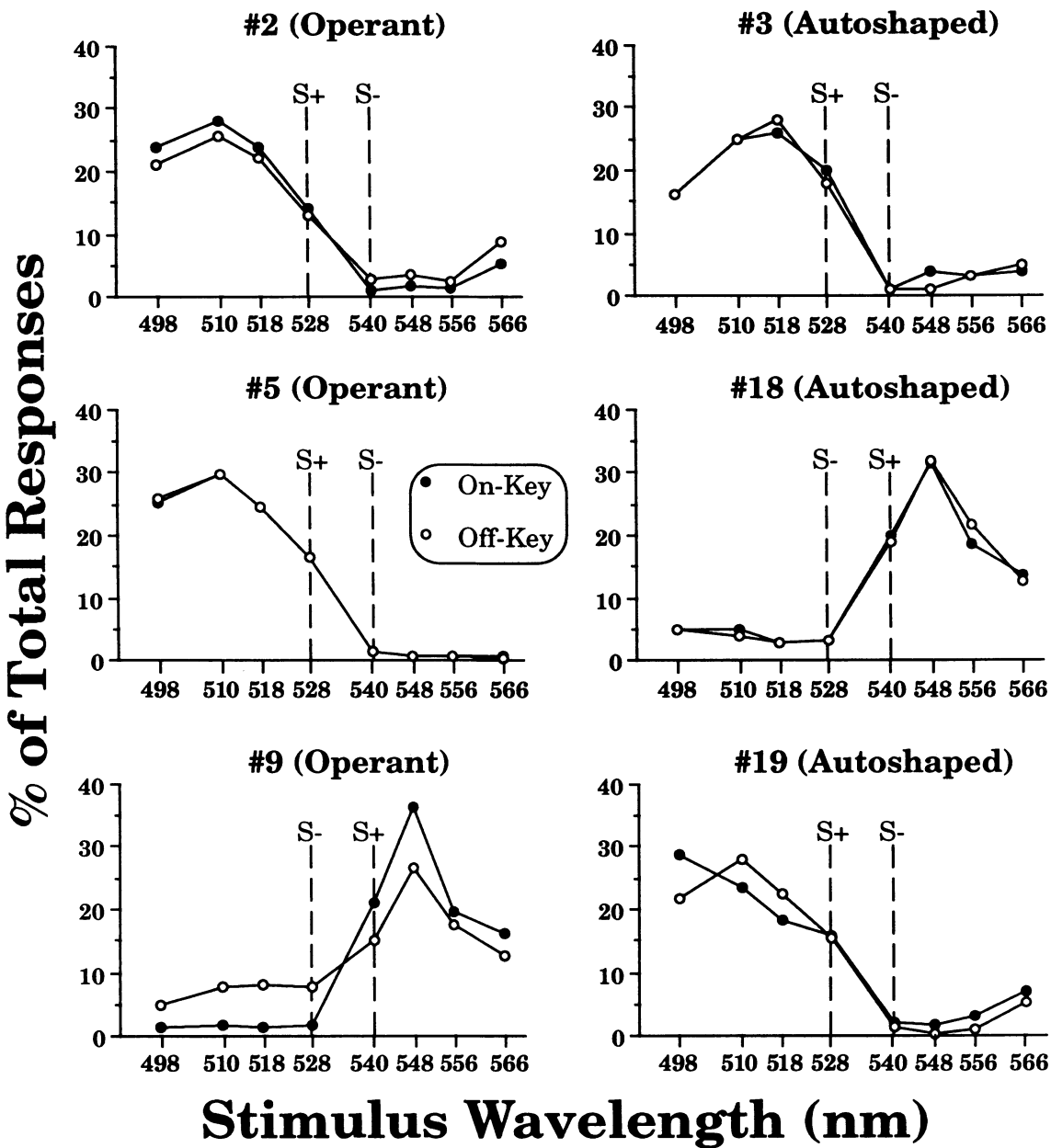


Fig. 4. Relative generalization gradients of on-key pecks and off-key pecks for birds in the operant group (left) and the autoshaped group (right). Each point on a gradient represents the percentage of total pecks, on-key (filled circles) or off-key (open circles), produced at that stimulus value by the subject. Two points are presented at each stimulus value. Overlapping points are represented as open circles.

shaped key pecks (Gamzu & Williams, 1971, 1973). According to this analysis, elicited key pecks should disappear when the stimulus-reinforcer contingency was eliminated for the autoshaped birds in the present experiment by programming VT 30-s grain presentation in

the presence of both 528 and 540 nm (Schwartz & Gamzu, 1977). That is precisely what happened to the pecking of all birds in the autoshaped group (Panel III of Figure 2). The essentially complete elimination of key pecking in the autoshaped birds by the mult VT VT

schedule confirms that their key pecks were elicited as a function of the differential stimulus-reinforcer contingency, and that adventitious operant contingencies did not contribute to these pigeons' key pecks. Further, the re-emergence of key pecking when the stimulus-reinforcer contingency was again differentially programmed for these birds (Panel IV of Figure 2) supports their elicited respondent nature. The relatively long, variable durations of the VT components in the present experiment, coupled with programmed reinforcement in only 75% of them, did not lend our autoshaping baseline to the traditional omission test of respondent control (cf. Sheffield, 1965; Williams & Williams, 1969) in which short, fixed-duration CSs are usually employed.

Panel III of Figure 1 shows what happened when a VT 30-s schedule was programmed in the former S- component of the operant group. Key-peck rates in S+, where the VI 30-s schedule continued to operate, were essentially unaffected by this manipulation for Birds 2 and 9 (except initially for the latter), whereas those of Bird 5 restabilized at approximately 50 per minute. However, the apparent positive contrast effect in S+ when the birds were re-introduced to the mult VI 30-s EXT schedule (see Panel IV of Figure 1) suggests that the mult VI 30-s VT 30-s schedule influenced stimulus control, as an additivity theory of contrast would predict (Schwartz & Gamzu, 1977). Overall, this assay is quite convincing in affirming that the behavior of birds of both groups was, in fact, under the control of their programmed contingencies.

Bird 3 received completely automated initial autoshaping. However, due to several conditioning failures described earlier, until pecking emerged, initial autoshaping sessions were modified such that the CS was presented when the pigeon was oriented towards the front wall. The 12-nm CS+:CS- separation (the smallest for which autoshaping has been produced to our knowledge) probably made this modification more important than if stimulus differences had been more pronounced. In any event, for conditioning to occur the CS should be in the subject's receptive field. There are two sources of evidence clearly indicating that timing initial CS presentations to occur within the pigeon's visual receptive field did not compromise the integrity of the classical conditioning procedure. First, the generalization test

Table 2

Off-key S+ response rates as a percentage of on-key S+ response rates for autoshaped and operant groups (pecks per minute).

Group	Subject	S+ baseline	S+ test	S++ test ^a
Autoshaped	3	63.2	77.3	89.1
	18	66.1	55.6	59.9
	19	115.5	95.8	96.3
	<i>M</i>	81.6	76.2	81.6
Operant	2	34.1	28.5	27.6
	5	41.7	61.0	50.4
	9	2.1	2.2	7.7
	<i>M</i>	26.0	31.0	28.6

^a S++ refers to the stimulus controlling the highest rate in testing.

results of Bird 3 were comparable to those of Birds 18 and 19. Second, both contingency assays revealed stimulus-reinforcer control for all autoshaped birds.

Extremely effective conditioning and discriminative performance were produced by the modified autoshaping procedure. Birds 18 and 19 were ready for testing after less than 10 mult VT 30-s EXT sessions. Nevertheless, their generalization test results were comparable to those of Bird 3, who received more than 50 sessions on that schedule. Thus, number of training sessions within this rather wide range (7 to 52) was not critical in shifting the peak of autoshaped key pecks.

Analyses of Peak Shift

Spence's (1937) gradient interaction theory predicts the occurrence of peak shift whenever the intradimensional values of the S+ and S- stimuli are similar and their collateral excitatory and inhibitory gradients are appropriately contoured. According to this formulation, the summative interaction of the S+ centered excitatory gradient and S- centered inhibitory gradient results in peak shift (see Rilling, 1977, Figure 8, p. 448). Spence's theory made no distinction between gradients resulting from operant or respondent contingencies. Therefore, because excitatory and inhibitory gradients for autoshaped pecks following interdimensional discrimination training have been reported (Tomie et al., 1976; Wessells, 1973), peak shift would be predicted following the appropriate intradimensional autoshaping. The robust and consistent peak shift produced in the present experiment, with autoshaped

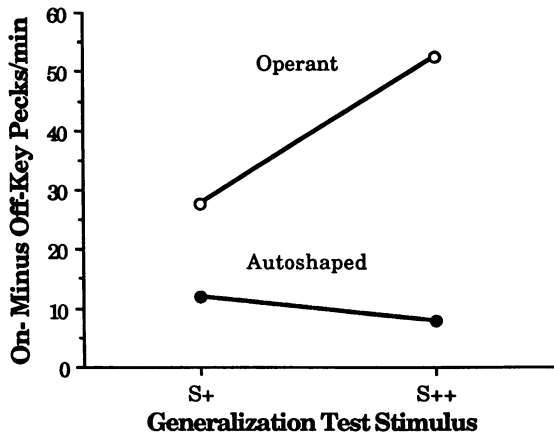


Fig. 5. Absolute difference between on-key minus off-key peck rates for operant group (open circles) and autoshaped group (filled circles) at S+ and S++ generalization test stimulus values. S+ is the stimulus reinforced in training (528 or 540 nm). S++ is the stimulus value that controlled a subject's peak rate in testing. S++ was always removed at least one stimulus value from S+ in the direction away from S-.

key pecks clearly under stimulus-reinforcer control, confirms respondent predictions from Spence's theory.

Although Spence (1937) made no distinction between operant and respondent control here, Weiss' (1971, 1977, 1978) two-factor model of stimulus control deals with the contribution of these different contingencies to the likelihood, and robustness, of peak shift. He observed that in the large majority of operant discrimination studies, the presence of S+ is correlated with an increase in both response and reinforcement frequency and argued that this covariation obscures the contributions of each contingency to the resulting stimulus control. Weiss' experiments separately measured and compared the contributions to stimulus control of the response-reinforcer and stimulus-reinforcer contingencies found in operant discrimination situations. Extrapolations from this research indicated that either source of control alone should be sufficient to produce discrimination-dependent phenomena such as peak shift. However, according to Weiss' formulation, peak shift would be enhanced when both contingencies produced excitation at S+, in comparison to the situation in which only one contingency was operating (see also Weiss & Schindler, 1987).

For the operant group in the present experiment, the increased key pecking in S+

produced by the response-reinforcer contingency created a correlated stimulus-reinforcer contingency in that stimulus. In comparison, the key pecking of the autoshaped group was solely the product of S+ being associated with an increased frequency of reinforcement. This permits a direct test of Weiss' two-factor algebraic combination model. When key-peck rates in S++ (peak-rate stimulus) were compared over groups, the additive prediction from the model was supported. The operant group's 73.8 pecks per minute to S++ was significantly higher than the 48.5 pecks per minute to S++ by the autoshaped group, $t(4) = 2.29$, $p < .05$, one-tailed. This significant superiority of the operant group at S++ was three times their 8.4 pecks per minute superiority (not statistically significant) at S+.

This superiority in S++ rates by the operant group, coupled with the between-group difference in off-key peck performance, produced the interaction profile shown in Figure 5. This profile is based on the absolute differences between on-key and off-key peck rates for each group at S+ and S++. The group effect was significant on this difference measure, $F(1, 4) = 9.42$, $p = .037$. Moreover, the significant interaction reveals that the on-key minus off-key difference did not change from S+ to S++ for the autoshaped pigeons, whereas this difference almost doubled for the operant pigeons, $F(1, 4) = 40.44$, $p < .003$. This is another indication of greater responding to the stimulus controlling maximum shift by the operant group than by the autoshaped group because off-key rates were a comparable percentage of on-key rates at S+ and S++ for both groups (Table 2).

As an algebraic combination model, Weiss' formulation also predicts a decrease in the likelihood of peak shift when, as a by-product of discrimination training, (a) the response-reinforcer contingency produces an increase in the operant at the stimulus value at which the implicit stimulus-reinforcer contingency produces respondent inhibition or (b) the response-reinforcer contingency produces a decrease in the operant at the stimulus value at which the implicit stimulus-reinforcer contingency produces respondent excitation.

Weiss and Dacanay (1982) developed a baseline schedule that permitted them to test both of these predictions simultaneously in the same subjects. Their experiment was briefly

described in the introduction. To recapitulate, they trained pigeons on a chained schedule in which treadle pressing in the initial-link wavelength (S2), presented on a key, produced the terminal-link wavelength (S1), where reinforcers were delivered according to a DRO schedule applied to the treadle press. Here, the operant and respondent by-products of discrimination training were conflicting at both S1 and S2 (one excitatory and the other inhibitory).

On this chain VI DRO schedule, over 95% of the treadle presses were emitted during S2, and most (94% to 99.3%) nonfunctional key pecks were elicited in S1 where all the food was delivered. However, in spite of these excellent intradimensional discriminations, generalization tests revealed no peak shift for the treadle-press operant, with even area shift attenuated. Moreover, their subjects produced sharp, symmetrical autoshaped key-peck gradients that peaked at S1, with area shift entirely absent for 2 of the 3 birds.

Consistent with predictions from Weiss' model, in the Weiss and Dacanay (1982) study, peak shift did not occur for the operant (treadle press) when primary reinforcement was absent during its discriminative stimulus (S2), and peak shift did not occur for the respondent (key peck) when during its CS (S1) operant behavior, maintained by the same reinforcer associated with the CS, was suppressed by the DRO contingency. That is a perfectly symmetrical, bidirectional, two-factor application. It contrasts with traditional unidirectional two-factor theory that considers only the effects of classical mediation on instrumental behavior (Rescorla & Solomon, 1967). The implications of a bidirectional two-factor theory to an analysis of stimulus control deserve further exploration.

CONCLUSION

This experiment has been successful in clearly and unambiguously producing significant generalization peak shift with autoshaped key pecks. Peak shift that can be considered respondent in nature has rarely been reported heretofore, and never this consistently and robustly. In addition, the contingency assays demonstrated, independently of the training procedures used, that the autoshaped birds behaved as classically conditioned subjects.

They produced significantly more off-key pecks than did the operant birds, and their pecking ceased when CS+ was no longer differentially correlated with reinforcement. This suggests that with the appropriate stimulus and training parameters, robust generalization peak shift should be forthcoming after intradimensional classical training with responses such as the rabbit's nictitating membrane or elicited jaw movement. However, if this classical training is to be functionally comparable to that of the autoshaped group in the present experiment, a two-component paradigm is necessary, in which the CS+ is an intradimensional change directly from the CS- stimulus condition. In traditional classical conditioning studies, the CS+ and CS- are separated by an interstimulus interval. Generalization peak shift of an autoshaped key peck remains to be demonstrated in a paradigm in which CS+ and CS- wavelengths projected on the key are separated by, for example, a dark key.

The generalization test results of the autoshaped group confirmed predictions of respondent peak shift that can be derived from Spence's (1937) gradient interaction theory. In addition, comparisons of the magnitude of the shift for operant and autoshaped groups indicated that in the former group the discriminative by-products of both the stimulus-reinforcer and response-reinforcer contingencies contribute to the strength of peak shift. This supported Weiss' (1978) two-factor model of stimulus control. The qualitative comparability of the gradients produced after stimulus-reinforcer and response-reinforcer discrimination training further confirms the similarity of perceptual processing in classical and operant learning.

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